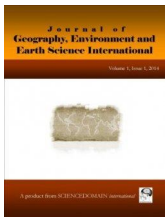

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Analysis of Morphology of Volcanic Craters on the Biu Plateau, Borno State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author JA designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author JOO managed the literature searches, analyses of the study performed the spectroscopy analysis and author BBW managed the experimental process and JA identified the craters, geomorphic processes and generated the DEM and 3D of the morphology of the craters. All authors read and approved the final manuscript.

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ABSTRACT

This research examined the morphology of volcanic craters on the Biu plateau with the aim of understanding their modification and processes acting on them. The objectives of the study are to identify the craters; determine the morphology and the geomorphic processes responsible for it. Data used for this study were generated from field observations, topographic map and total station. Three sampled craters namely Kumba, Tilla and Jali Tagurmi were purposively selected for the study. GIS software (ILWIS) and Surfer 7.0 was used to produce the DEM and 3D from the data generated using the total station. Results showed that there are fourteen craters on the Biu Plateau; four large (> 300 meters) in diameter, five medium (200-300 meters) and five small (< 200 meters). The morphology of the Kumba crater is conical with an elevation range of 700 meters to 765

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meters, Tilla crater is circular with elevation range of 736 m to 742 m while the Jali Tagurmi crater has an oval shape with spot height of 690 meters to 740 meters above sea level. Denudational processes observed on the rims of the craters include weathering, sheet, rill, gully erosions and mass wasting (rock fall, soil creep, debris creep and slides). From the findings of the research it suggests public education on sustainable environmental management of land based resources.

Keywords: Volcanic crater; geomorphic processes; morphology and Nigeria.

1. INTRODUCTION

The Biu Plateau is a topographic divide (or watershed) between the upper Benue to the south and the Chad Basin to the north. The plateau has a volcanic area of 5,000 square km, characterised by series of volcanic cones, volcanic lava flow ridges, volcanic scarp slopes, craters, crater lakes and breached crater rims. The plateau surface consists of undulating plains lying between 600-800 m [1] above sea level; formed over a series of overlapping horizontal lava flows Turner [2]. According to Rankenburg et al. [3] the volcanic craters on the Biu Plateau that form part of the Cameroon Volcanic Line is composed of basaltic lava flows. It is characterized by number of recent cinder cones with well-defined craters aligned in a NNW-SSE direction. The cinder cones and lava flows on the Biu Plateau often contain abundant peridotite xenoliths. Salzmann [4] put the age of the volcano is 840,000 years ago.

A volcanic crater is a relatively circular depression on the earth's surface caused by volcanic activity. It is a basin, within which a vent is located from which lava had erupted or will in form of gases, and ejecta. A crater can vary in size and depth. During volcanic eruptions, the volcano's magma chamber may be evacuated from the area above it and subside to form a crater or a caldera. In initial or primary volcanoes, the crater is situated at the top of the cone that is formed by pyroclastic materials (or debris). In sequential or secondary volcanoes the craters may be situated on the flanks of volcanoes and these are commonly referred to as flank craters. Most volcanic craters may either be fully or partially filled with runoff or melted snow to form a crater lake.

Volcanoes are spectacular landforms produced by the effects of the internal processes such as volcanicity, earthquakes, compressional, tensional and subsequently modified by external ones such as weathering, erosion, transportation, deposition, landslides. Examples of volcanic features include volcanic hills, valleys, plateau and crater [5]. Howard and Spock [6] defined a landform as any element of the landscape characterized by a distinctive surface expression, internal structure, or both and sufficiently prominent to be included in a physiographic description. The present day landform is a result of different geomorphic processes such as weathering, erosion, transportation and deposition over geological times.

A basic understanding of the general configuration of landforms, the surface processes and environmental factors involved in their modification is necessary, especially in volcanic landscapes like the Biu Plateau. Such understanding will assist in the effort to improve, maintain and predict the sustainability of the physical environment and reduce the impact of contemporary earth surface processes that lead to natural hazards such as landslides, gully erosion and floods.

1.1 Statement of the Problem

Biu is a volcanic plateau, characterized by various spectacular geomorphic features which make the area very unique in terms of height, rainfall, temperature, soil, vegetation, climate when compared to its surrounding environment. Some studies consider the Biu Plateau as the end of the North-North West (NNW) branch of the continental sector of the Cameroon Volcanic Line (CVL) [2,7,8,9]. According to Amaza et al. [10] various agricultural activities on the Plateau have led to the modification of the plateau. Bwala [11] focused on the domestic water availability and utilization on the Biu Plateau. He concluded that the Plateau is the major source of both surface and underground water in the area. However, no known study has focused on the analysis of the morphology of the volcanic craters on the Biu plateau. The purpose of the study is to conduct a morphological study of a Biu plateau due to the anthropological activities taking place. A study of the morphology is absent and this study will explore the relief of the area in order to assist in decisions on how the natural resources on the plateau can be accessed and exploited.

1.2 Aim and Objectives of the Study

The study examines the morphology of volcanic craters on the Biu Plateau with a view to understanding their modification and present processes responsible or acting on them. The study has the following objectives:

i. to identify the craters on the Biu Plateau;
ii. to examine the geomorphic processes in the craters;
iii. determine the morphological dynamics of the craters;

1.3 Research Questions

i. How many craters are there on the Biu plateau?
ii. What are the geomorphic processes involved?
iii. What are the morphological changes occurring on the craters?

2. METHODOLOGY

The various methods used to obtained data in this study are presented in this section. Included in this section are sources of data, sampling techniques and methods of data analysis.

2.1 Sources of Data

Both primary and secondary sources of data were used in this study. The primary data include the use of Total Station Survey Instrument in generating data for producing the DEM and three- Dimension (3-D) view of the sampled craters. Secondary sources of data included the Biu topographic Sheet 133 (1:100,000) and earlier studies by Amaza et al. [10] among others. Through the use of the Integrated Land and Water Information System (ILWIS) GIS software, the Digital Elevation Model was produced showing the morphology of the craters.

2.2 Sampling Techniques

Using the topographic map of Biu sheet 133 on the scale of 1:100,000 and ground truth, the craters were categorised into three major groups based on the diameter of their rims as follows: Large (> 300 meters), Medium (200–300 meters) and Small (< 200 meters).The craters with rim diameter less than 200 meters is termed as a small rim size, those with rim sizes between 200-300 meters as Medium rim sizes and those with rims greater than 300 meters as large rims. Purposive sampling technique was used to select one crater from each of the three categories for detailed study.

2.3 Generation of the Craters' DEM

The Biu Topographic Sheet 133 (1:00,000) as shown in Fig. 1 was scanned from the Corel Draw environment and exported (as tagged image file-TIFF file type). Geo- referencing processes were performed using the ILWIS environment so that the pixel of the maps conforms to the precise coordinates of the points they represent on the ground. The contour lines on the topographical map representing all area having the same heights above the sea level were digitized and interpolated in the ILWIS environment where the Digital Elevation Models (DEM) were created. The DEM was used to generate the 3D module of ILWIS software for clearer view.

2.4 Total Station for Morphology Survey

Total Station is a surveying instrument commonly known as Electromagnetic Distance Measurement (EDM) Fig. 1. It was used for generating data about the morphology of the three craters. The instrument generated data on the Easting, Northing and Height commonly known as X, Y, Z that was used in producing the DEM and 3D. The observations were made at intervals of ten meters from the base across each of the three craters and the X, Y, Z; data were recorded as shown in Fig. 1.

The data generated from the Total Station Survey instrument, Global Position System and field observation were analysed using the AutoCAD and Surfer 7.0 software.

3. RESULTS AND DISCUSSION

3.1 The Craters on the Biu Plateau

Using the Biu Sheet 133 (1:100,000) and ground truthing, four large craters, five medium size craters and five small craters were identified which gives a total of 14 craters on the Biu plateau as shown in Fig. 1and Table 1.

Fig. 1. Sampling at Kumba crater using total station (SOKKIA 630R)
Source: Fieldwork, 2014

Table 1. Inventory of craters on the Biu Plateau

S/No	Large (> 300 m)	GPS Coordinates (Northing)	Easting
1.	Kumba Crater (Gar Kidi)	10º 48'20.486'' N	12º 7'81.533'' E
2.	Gurara Crater (Gar Gurara)	10º 36'36.616'' N	12º 9'43.291'' E
3.	Zamta Crater (Gar Zamta)	10º 40'56.895'' N	12º 1'13.285'' E
4.	Padam Crater (Gar Padam)	10º 50'47.798'' N	12º 7'22.654'' E
	Medium (200-300 m)		
5.	Kidi Crater (Gar Kidi)	10º 46'20.485''N	12º 7'8.153'' E
6.	Hujiga Crater (Gar Hujiga)	10º 49'26.901''N	12º 4'16.184''E
7.	Kufakana Crater (Gar Kufakana)	10º 44' 31.449''N	12º 9'11.084''E
8.	Hizhi Crater (Gar Hizhi)	10º 40'28.757'' N	12º4'42.026''E
9.	Tilla Crater (Gar Tilla)	10º 39' 50.066''N	12º 8'47.014''E
	Small (> 200 m)		
10.	JaliTagurmi Crater (Gar JaliTagurmi)	10º42'38.896''N	12º 7'40. 186 E
11.	Tilla Crater (NkwarTilla) (Gar NkwarTilla)	10º38'37.079''N	12º 9'57.136''E
12.	Sugur Crater (Gar Sugur)	10º44'34.966''N	12º 5'58.185''E
13.	Pidarta Crater (Gar Pidarta)	10º55'22.147''N	12º 0'27.156''E
14.	Sugwi Crater (Gar Sugwi)	10º53'15.524''N	12º 1'29.767''E

The craters are significant on the DEM Fig. 3 they are shown in red colour. The result also revealed that the pattern of the distribution of the craters on the Biu plateau is not evenly distributed as most of the large, medium and small craters with the exception of Tilla and NkwarTilla are all located around the Miringa volcanic area. The distribution is more or less linear in pattern as shown in Fig. 1.

3.2 Morphological Dynamics of the Craters

A close look at the three dimension model in Fig. 3 (DEM) reveals a clearer view of the morphology of the craters in terms of size and their shapes. Their precise locations also agreed with the GPS coordinates obtained during the ground truthing when the inventory of the craters was taken. It was observed that the volcanic cones have well defined craters with breached rims and steep slopes. Areas in deep blue colour are low lands which range from 416 meters to 524 meters above sea level. Areas in light blue and light brown are relatively higher; they range from 524 meters to 659 meters above sea level and serve as escarpments joining the lowlands and the plateau. The areas in red are the highlands of the mountainous southern part of the study area. The red dots in Fig. 1 are craters located on top of the Plateau.

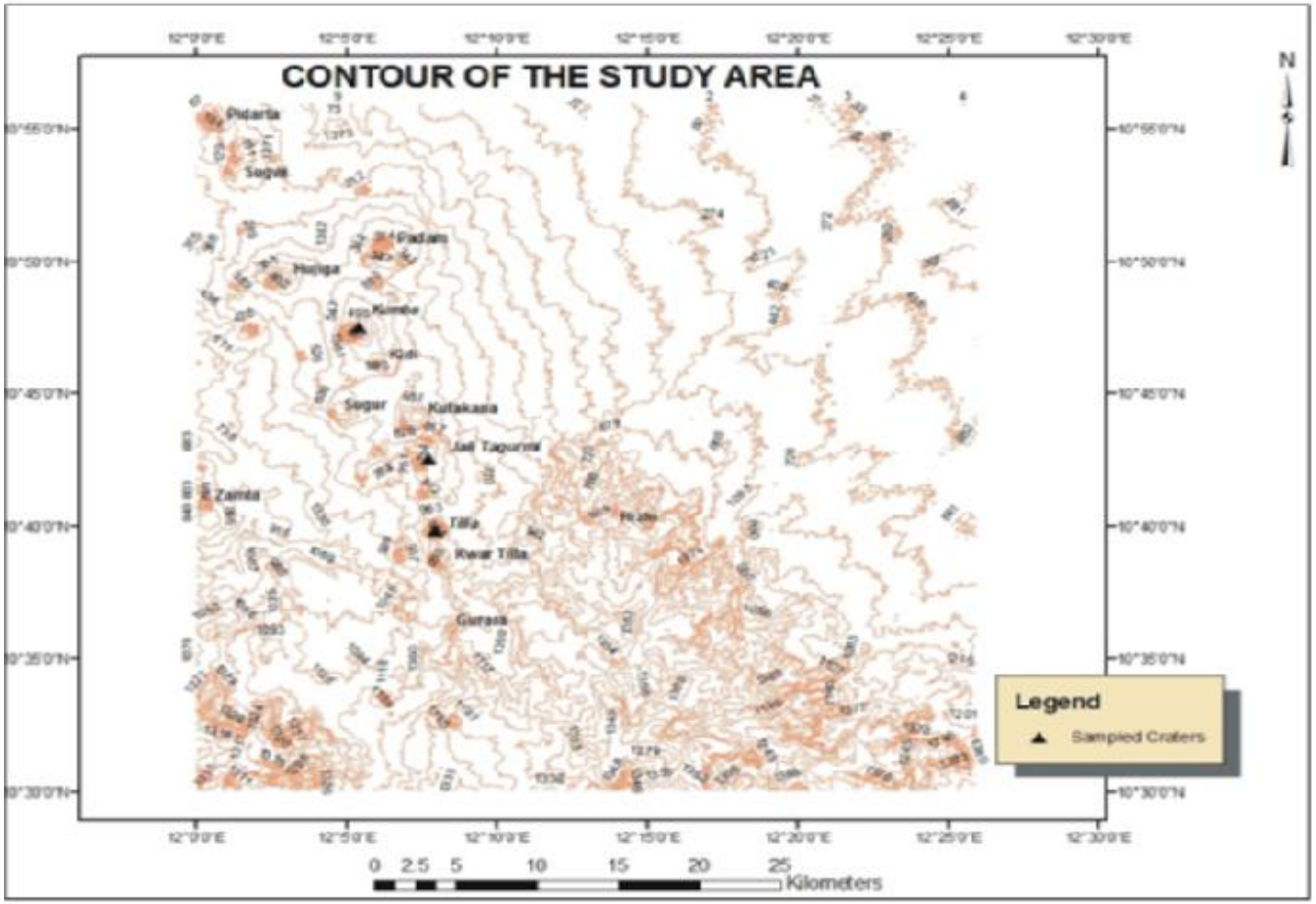

Fig. 2. Distribution of craters and sampled craters on the Biu Plateau
Source: Topographic Map Sheet 133 of Biu Plateau

The morphology of the three craters were analysed through the use of the three Dimension (3D) mapping of the Biu plateau that was produced as explained earlier. The craters and the mountainous area in the western part of the area are shown in red colour. Their pattern of distribution could be described as fairly dispersed but with some concentration of the volcanoes (volcanic craters) at the middle of the map.

(a) Morphology of Kumba Crater

The Kumba crater could be described as the largest among all the fourteen craters identified in the area with diameter of 375 meters as shown on the 3 D) map in Fig. 4. The morphology is conical in nature with elevations between 700 meters and 765 meters. These are depicted in light brown and blue colours respectively in Fig. 4. The floor of the crater is shown in white colour with a height of 740 meters which also conforms to the height obtained from the profile in Fig. 4. The circumference of Kumba is 1100.13 meters.

(b) The Morphology of Tilla Crater Lake

The morphology of Tilla Crater could be described as conical in shape as clearly shown in Fig. 5. The map shows that the highest point (dark blue) is 770 meters while the lowest point (light brown) which forms the floor of the Lake is 715 meters. The circumference of Tilla Crater is 1051.96 meters. The diameter of the water body in Tilla Crater Lake is 800 meters. Contrary to the earlier observation by Davies [12] that Tilla Crater is the largest on the Biu Plateau, this study reveals that Kumba Crater is the largest crater on the plateau. In relative terms, Tilla Crater is located closer to Biu town, it is more accessible, attractive and better known to people than Kumba. One of Tilla crater's natural attractions to both tourists and local people is its capacity to retain water all year round which makes it a perennial water (re)source.

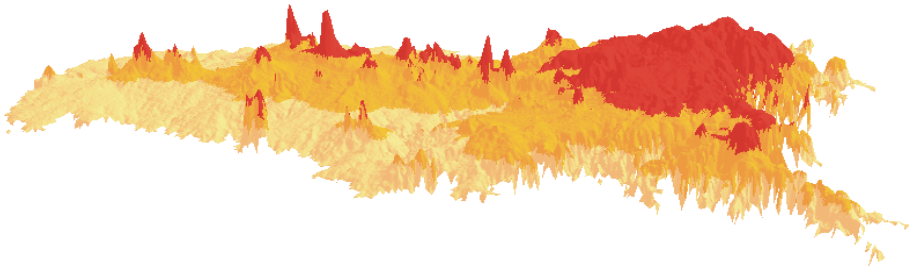

Fig. 3. Three dimension of the Biu Plateau showing the craters

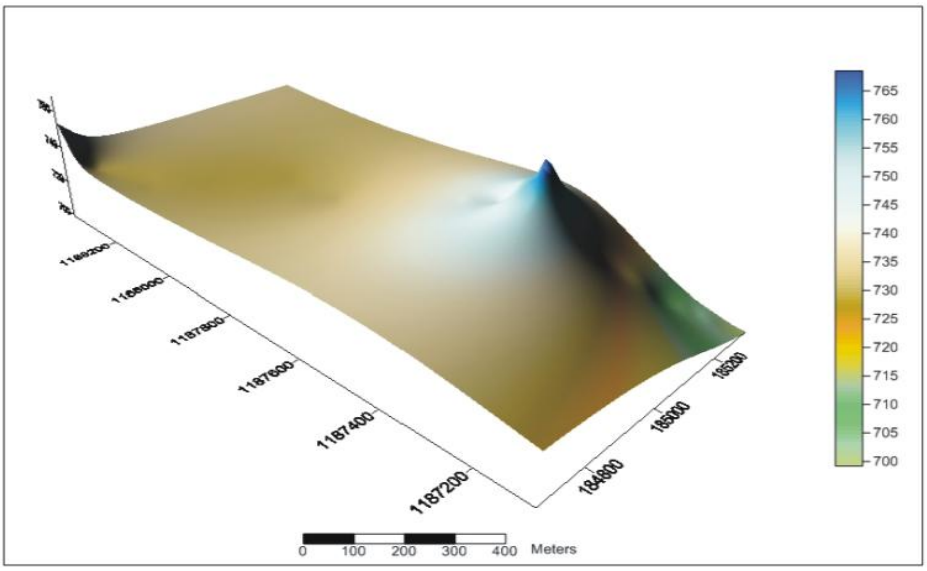

Fig. 4. Three dimension (3D) of Kumba crater

(c)The Morphology of Jali Tagurmi Crater

The morphology of the Jali Tagurmi Crater could also be described as conical in nature similar to that of Kumba even though Jali Tagurmi is smaller in size as shown in Fig. 6. The lowest point of 736 meters on the rim or crest is shown in blue colour in the Western part while the highest point of 742 meters is shown in dark blue colour in the Eastern part of the crater. The floor of the crater is shown in white colour with a height range from 724 meters to 732 meters (Fig. 6).

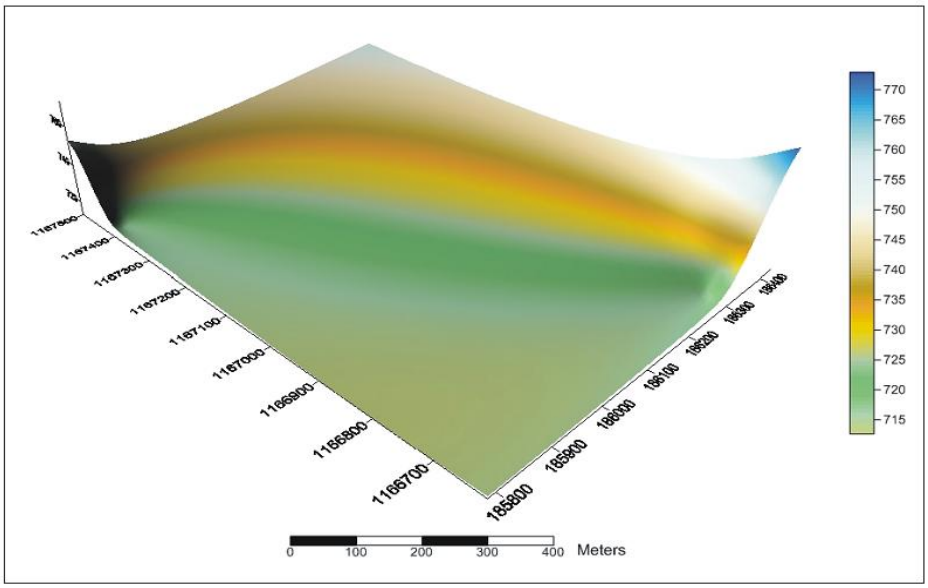

Fig. 5. Three dimension (3D) of Tilla Crater Lake

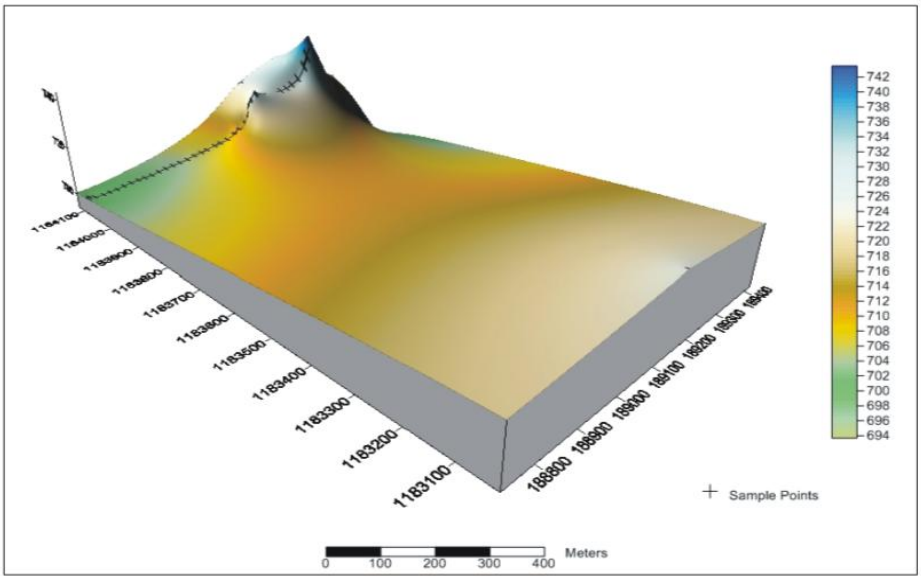

Fig. 6. Three dimension (3D) of JaliTagurmi crater

3.3 Dynamics of the Geomorphic Processes at the Craters

Since their formation, the volcanic craters have changed over time in terms of their heights, thickness and depths. These could be attributed to geomorphic processes of weathering, erosion, transportation and deposition. In this section, the geomorphic processes that have modified them are presented.

(a) Climate

According to Ijere and Mailafiya [13], the Biu Plateau has an annual rainfall between 600-1200 mm. The rainfall and temperature patterns as observed in Biu Town over the past two decades are shown in Fig. 7. The rainfall amount, duration, intensity and frequency have contributed to the modification of the craters. Biu Plateau has unique weather and climate conditions compared with the surrounding environment. The rainfall, temperature and humidity are localised due to the effect of the altitude. The high temperature and humidity in the area also have contributed towards the physical and biological weathering that aids geomorphic processes that modified the craters.

(b) Vegetation

Biu plateau is located in the Sudan Savanna type of vegetation in Nigeria [1]. Field observation reveals that the Plateau is characterised by scattered trees, shrubs and grasses. The grasses are denser during the wet season and dry up during the dry season when they are subjected to bush fire. These grasses include elephant and gamba grass while trees are Baobab (*adansoniadigitata*) and *Acacia radian*. The trees are characterised by long tap roots and hardback. They also shed their leaves during the dry season as a way of reducing the rate of water loss through transpiration during harsh weather conditions [1]. The sparse nature of the vegetation which is characterised by scattered trees and shrubs could not protects the soils from splash, sheet, rill and gully erosion as observed to be major geomorphic processes modifying the craters.

(c) Slope as a Factor of Geomorphic Processes

Slope is an important feature of craters. The slopes at the three crater sites, Kumba, Tilla and Jali Tagurmi were studied and the roles they have played in geomorphic processes were observed and measured. The results of the measurements and field observations at the craters show that slope plays an important role in the geomorphic processes at the three craters.

Tilla Crater has no foot slope and could be attributed to its morphology. The crest slope (rim) is characterised by gradient of 21º that serves as the water shed that drains water into the crater. Fifty meters from the crest into the crater is characterised by steep slopes with gradient ranging from 35º to 26º. The steep slope is extended by a gentle slope with a gradient of 23º which is characterised by gully as observed during the study. The study revealed that materials eroded from the crest of the rims are transported along the slope and finally deposited between slope angles of 1º to 5º and on the floor of the crater.

Jali Tagurmi crater could be described as the smallest with an oval shape. It is characterised by a foot slope. The gradient keeps increasing from 1º to 8º as one ascends from the main road to the crest of the crater. The crest (rim) which serves as the divide is associated with a gradient of 17º followed by a steep slope with a gradient of 30º. From the eastern part of the crest which is the highest point on the rim is associated by steep slopes with gradients range from 39º to 53º. The floor of the crater is joined to the steep slope with gradients of 5º and 21º. It was observed that the slopes contributed in the generation of runoff from the crest of the crater which aids the removal and transportation of eroded materials. This contributed towards the modification of the morphology of the craters on the Plateau.

The Kumba crater is characterized by a rim which serve as the crest or divides that drains water outside or into the crater. Kumba crater has eleven segments starting from the crest down to the floor. The geomorphic processes observed at the foot slope were deposition of materials eroded from the crest. The rim of Kumba crater is characterized by steep slope with external gradients range from 36º to 43º while internal gradients ranging from 35º to 36º. This means that the slope is steeper as one ascend the crater than while descending on the floor. This implies that more materials are deposited inside the crater thereby reducing the depth of the crater.

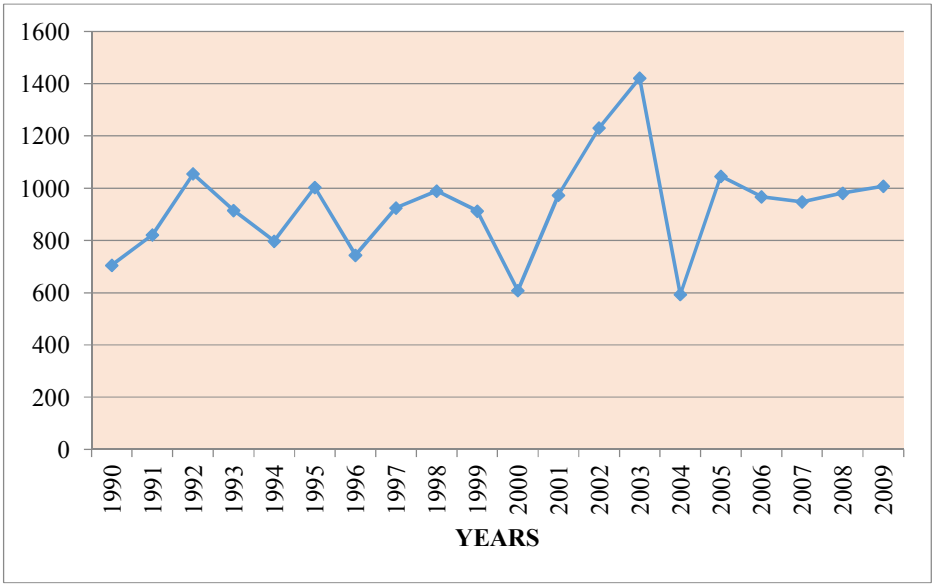

Fig. 7. Biu annual rainfall from 1999 – 2009

(d) Man's Activities

It was observed in the course of the study that various socioeconomic activities are taking place in and around the craters. These include farming, overgrazing, mining, bush burning, fuel wood extraction and deforestation. These human activities in and around the craters have resulted into accelerated geomorphic processes such as splash, sheet, rill and gully erosion that contributed toward the modification of the craters.

4. SUMMARY

Biu is a volcanic plateau, characterized by various spectacular geomorphic features including craters and crater lakes which make the area very unique in terms of height, rainfall, temperature, soil, vegetation, climate when compared to its surrounding environment. The study established that there are 14 craters on the plateau. The height of the rim of the three craters which form the focus of the study range from 700 meters to 765 meters above sea level. The study also reveals that the surface of the plateau has been modified due to natural processes such as erosion and weathering and anthropological activities including settlement, farming grazing, mining, bush burning, fuel wood extraction and deforestation occurring on the plateau. These human activities in and around the craters have resulted into accelerated geomorphic processes such as splash, sheet, rill and gully erosion. These processes will continue to exert a strong influence on the morphology of the plateau in general and the craters in particular over time.

5. CONCLUSION

The Biu Plateau is a scenic geomorphic environment with many craters. Occurring on the plateau the general elevation of the craters is remarkably higher than the surrounding lowlands. However, slope processes have combined with as well as accelerated by human activities such as settlements, farming and grazing to modify the craters and their slopes through weathering and erosion. If these human activities are not stopped or meaningfully controlled, the craters on the plateau will continue to greatly and rapidly modified.

6. RECOMMENDATIONS

Based on the findings of this study the following are recommended:

There is a need for adaptation of appropriate soil conservation strategies by the local communities and the State Government based on a thorough understanding of the processes and factors aiding erosion in and around the craters so as to reduce the rate at which the morphology of the craters are modified.

Human activities in and around the craters should be well controlled by the local authority so as to ensure sustainable use of environmental resources associated with the craters.

The local communities residing around the craters should be educated by the local authority about the dangers associated with their activities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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